Effects of initial alpha wave abundance and operant training procedures on occipital alpha and beta wave activity*

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Operant methods were used to increase differentially the abundance of occipital EEG waves in the alpha (8-12 Hz) and beta (above 13 Hz) frequency bands of naive undergraduate Ss in the presence of a discriminative stimulus. Ss were grouped by the amount of alpha wave activity in their pretraining EEG. Operant training with continuous reinforcement produced reliable and orderly changes in EEG spectra as a function of reinforcement contingency. Baseline alpha abundance predicted only the mean level of alpha output over trials, not the efficiency of training. Matched yoked controls showed no difference in EEG spectra between the two reinforcement conditions.

It has been reported recently that human Ss may alter the spectra of their EEG activity if they are provided feedback indicating the level of activity in the frequency band which is to be augmented or reduced (Kamiya, 1968; Nowlis & Kamiya, 1970; Green, Green, & Walters, 1969; Brown, 1970). Previous attempts to condition cortical alpha activity classically met with limited success (Jasper & Shagass, 1941a, b; Shagass, 1942; Shagass & Johnson, 1943; Wells & Wolff, 1960; Albino & Burnand, 1964; Torres, 1968). In the current work of Kamiya (1968), Nowlis & Kamiya (1970), and Green et al (1969), the training methodology is presented primarily in terms of feedback operating in a cybernetic control system. Ss are presented with displays which indicate the amount of alpha band activity in S's recent EEG. Other models also fit this methodology. Since Ss in these experiments are presumably motivated to control their EEG patterns, feedback may be considered to operate as a reinforcer in an operant conditioning paradigm with a continuous schedule of reinforcement.¹

The present study is based on the operant model of response modification. It represents an attempt to gather basic data on the control of EEG alpha and beta activity in a normal and relatively unselected population of undergraduate students. The use of the operant theoretical framework suggests some appropriate control procedures which have not been previously employed. To show experimental control of EEG activity, Ss were trained in a mixed set of trials

to increase either occipital alpha or beta activity, contingent on the state of a visual discriminative stimulus (SD). To show that it was, in fact, the contingency of response and reinforcement that was responsible for any observed alteration in the experimental groups, a group of yoked controls which received noncontingent reinforcement was also employed. Since a fairly large number of Ss was studied, the suggestion that the efficiency of training is related to the initial abundance of alpha activity (Nowlis & Kamiya, 1970) was systematically tested.

SUBJECTS

Thirty-six undergraduate students served as Ss in order to partially satisfy the requirements of an introductory psychology course. Ss were assigned to this experiment without prior knowledge of its nature. This procedure was thought to minimize problems stemming from the self-selection of Ss.

ELECTRICAL RECORDING

Occipital EEG was recorded from position O₂ of the 10-20 system (Jasper, 1958) referred to the right earlobe. S's left earlobe was grounded. The EEG was first amplified by a Grass P-15 amplifier and then by a series of integrated circuit amplifiers with active filters. The frequency response of the total system was essentially flat between 2 and 20 Hz, with ½ amplitude attenuation at 0.6 and 32 Hz. This signal was monitored on an oscilloscope and was available at the analog/digital converter of the computer.

DESIGN AND PROCEDURE

The Ss were first told that they were participating in a study of brain wave activity. After the recording electrodes were attached, Ss were seated in an electrically shielded room with a low level of ambient lighting. They were asked to keep their eyes

open and refrain from moving for a 300-sec period, during which the computer calculated the baseline spectra of their EEG. Ss were then instructed as to the nature of their task, in words similar to the following: "While you have been sitting here, the computer has made a number of measurements of your EEG activity. You now have the opportunity to learn to control your own brain waves. The EEG is a complex waveform which may be thought to show many different patterns. From all these patterns we have arbitrarily selected two for today's study. Each second the computer will sample your EEG, looking for one of the two selected wave patterns. Light 1 signifies that the computer is looking for Pattern 1, and Light 2 means Pattern 2. When Light 3 is on, you may rest. When it finds what it is looking for, the loudness of the background tone will be increased for 1 sec. Your job is to learn to produce the kinds of wave patterns which will keep the tone on. If you succeed in doubling either kind of EEG activity from your baseline level, you will receive an extra hour of experimental credit. If you double both, you will receive 2 free hours of credit. As before, keep your eyes open and refrain from moving."

Twenty-seven Ss were then run for 10 experimental training trials of 200-sec duration. Training was divided into five blocks of two trials, one with alpha reinforcement and one with beta. The ordering of trials within a block was random. Between blocks, Ss were forced to get up and walk around for a period of not less than 1 min. No mention was ever made of alpha waves, cortical desynchronization, or similar matters during training, nor was there any discussion of the psychological states which are thought to be associated with these phenomena. Between trials, Ss were given general indications of their success in achieving control.

The 27 experimental Ss were divided, on the basis of baseline data, into low, medium, and high alpha groups of nine Ss each. Nine additional Ss served as yoked controls. They were treated in exactly the same manner as experimental Ss, except that their pattern of reinforcement was not contingent upon their EEG. Instead, their baseline spectra were used to match them with a single experimental S. The paper-tape record of that experimental S's reinforcements was used by the computer to generate the reinforcement pattern for the control S.

COMPUTER CONTROL

The entire experiment was run under digital computer control. During a trial or baseline period, the EEG was

*This research was supported by the Advanced Research Projects Agency of the Department of Defense and was monitored by the Office of Naval Research under Contract N00014-70-C-0350 to the San Diego State College Foundation.

Fig. 1. The probability of sampling a wave in the alpha (top row) or beta (bottom row) frequency band is given for experimental Ss with low, medium and high levels of baseline alpha and for control Ss as a function of baseline or trial block. "A" curve denotes alpha and "B," beta, reinforcement contingency.

sampled each second for one complete wave, referenced to 0 potential and beginning with a positive deflection. The period of this wave was then measured and classified by the method of Legewie & Probst (1969) as a single wave at X Hz. If the wave was within the criterion frequency band (8-12 Hz for alpha, 13 Hz or more for beta), the intensity of a quiet 400-Hz tone was augmented for 1 sec. During that second, the sampling and measurement procedure was repeated and, if that wave was also within the criterion bounds, the tone intensity remained high for another second. During the baseline trial, the tone was totally suppressed. After each trial, a count of the number of waves at each frequency was printed out and a record of the temporal pattern of reinforcement was punched on paper tape.

RESULTS

The data of this investigation are summarized in Fig. 1, which shows the probability of obtaining an alpha (top row) or a beta wave (bottom row) for each group, reinforcement contingency, and trial block. It can be seen that all experimental groups show differentiation of their EEG activity between the alpha and beta trials. Thus, alpha wave activity (seen in the top row of Fig. 1) is more

probable during alpha than during beta reinforcement. Further, these differences increase with practice, as a function of trial block. These conclusions are supported by an analysis of variance (ANOVA) for the probability of alpha waves in the experimental groups. In the alpha ANOVA the effect of reinforcement contingency is clearly significant ($F = 21.84$, $df = 1/24$, $p < .001$), indicating that our Ss had shown differential control of alpha wave production as a function of the state of the discriminative stimulus. The significant interaction of Reinforcement Contingency by Trial Block ($F = 4.49$, $df = 4/96$, $p < .0025$) supports the conclusion that this differentiation increases reliably with practice.²

It appears that the baseline level of alpha activity is related to the mean level of alpha wave production on the subsequent trial blocks ($F = 4.64$, $df = 2/24$, $p < .025$). But the lack of a significant interaction between alpha wave abundance, group, and trials ($F = 0.487$, $df = 8/96$) fails to support the view that initial alpha wave abundance is a major determinant of the relative efficiency of learning differential control. Similarly, the correlations are neither large nor positive between baseline alpha wave

abundance and either the change in alpha activity between baseline and Block 5 ($r = -0.15$, n.s.) or the difference in probability of alpha activity between alpha and beta trials in Block 5 ($r = -.20$, n.s.). The probability of alpha wave on the last alpha reinforcement trial is, of course, significantly related to level of baseline alpha ($r = .43$, $p < .05$).

Reinforcement contingency also effects occipital desynchronization. It may be seen in the bottom row of Fig. 1 that for experimental Ss the probability of beta frequency activity is greater during beta than during alpha reinforcement. The ANOVA for the beta wave probabilities in the experimental groups reveals less order in this data than was seen above with the alpha probabilities. As with alpha wave activity, the effect of reinforcement contingency is highly significant ($F = 26.13$, $df = 1/24$, $p < .001$). Ss showed more beta wave activity on those trials in which it was reinforced. No other main effect or interaction approached significance. There is no evidence in this analysis for systematic effects of any consequence of trial block or baseline level of alpha on the probability of beta frequency activity. Similarly, no significant correlation was found between alpha or beta baseline and

any of the measures of beta activity used (probability of beta activity in Block 5, the difference in the probability of beta activity between the reinforcement contingencies in Block 5, or the change in the probability of beta activity during beta reinforcement between Blocks 1 and 5). Knowledge of the baseline spectra is of little use in predicting the probability of beta frequency activity and its changes in this task.

Separate analyses of the variance of the probability of alpha and beta activity were computed for Ss in the yoked control condition. Neither analysis reveals a significant effect of reinforcement contingency, trials, or their interaction. The yoked controls, unlike the experimental Ss, fail to show any differential response between alpha and beta trials. This argues that the contingency of reinforcement and response is necessary for the development of EEG control in our situation.

DISCUSSION

As has been previously reported, Ss can significantly and differentially increase the amount of alpha and beta activity in their occipital EEG when given feedback information or immediate reinforcement. Several aspects of the present study, however, should be emphasized. First, the amount of time spent in training was relatively short—16.6 min under each reinforcement contingency. Nevertheless, the effects of training are quite reliable and reasonably large. Differential responsiveness is evident after the first trial block.

Second, care was taken not to inform our Ss that the states to be discriminated were occipital alpha and desynchronization. These words currently trigger explicit expectations among a considerable subset of the undergraduate population, the effects

of which upon the learning situation would be unclear.

Third, the suggestion that initial alpha wave abundance is related to the efficiency of training is not empirically verified. Although an examination of Fig. 1 suggests that the medium and high groups show a more reliable differentiation between conditions, the correlational analysis does not support this view. One can predict reliably only that the final level of alpha wave activity will depend on the pretraining level. The efficiency of training does not depend in any important way upon initial alpha abundance, within the normal range of variability.

Fourth, the total failure of the yoked control Ss to learn or to show a significant response change with trials provides good evidence that it is, in fact, the response-contingent feedback or reinforcement which is responsible

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NOTE

1. The meaning of "continuous reinforcement" becomes less clear when the response to be reinforced is a particular configuration of a continuous analog signal such as the EEG. Nonetheless, the notion of scheduling reinforcement may be applied to such data as we show in a forthcoming paper, "Control of occipital EEG activity: Effects of the schedule of reinforcement."
2. The univariate ANOVA is biased toward overestimating the significance level of data based on repeated measures, if the correlations between these measures are not equal. To guard against this possibility, the Geisser-Greenhouse conservative F test (1958), which assumes the worst case of unequal correlation, was also used to estimate the minimal level of significance of the Trials by Reinforcement Contingency interaction. This interaction remains significant with $p < .05$.